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Behaviour of $Mg_{0.8}Zn_{0.1}Mn_{0.1}Al_{0.8}Fe_{1.2}O_{4+\delta}$ under the influence of X-band microwave radiation

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Abstract : The microwave transmission and reflection coefficients from 7.8 to 10.5 GHz of mixed ferrite in pellet form of composition $Mg_{0.8}Zn_{0.1}Mn_{0.1}Al_{0.8}Fe_{1.2}O_{4+\delta}$ of different thickness from 0.62 mm to 6.00 mm is reported in this paper. The transmittance and reflectance show a marked thickness dependency at particular frequencies where transmittance (voltage) becomes greater than one and reflectance (voltage) is also very high. Presence of complex and spurious modes superimposed on the dominant mode along with crystalline distortions might be producing dimensional resonance effects in the ferrite.

Keywords : Mixed ferrite, microwave transmittance, spurious modes

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1. Introduction

Ferrite elements are an important component of many microwave circuitry and non-reciprocal microwave integrated circuits. It is essential that the microwave properties of the material are known, to enable to perform the necessary trade offs in selecting specific materials. The behaviour of magnetized ferrites under the influence of d.c. magnetic field has been studied by various authors [1–5]. The static magnetic fields applied to the ferrite, influence the microwave properties. It would be more advantageous to use a non-magnetic ferrite as substrate with magnetically active zones to have non-reciprocal microwave component in truely planer form. With this in view, the preliminary study of the microwave properties of non-magnetic mixed ferrite was undertaken. Understanding the microwave behaviour of bulk samples will help in proper designing of ferrite components in thin film form, as these bulk samples will be used as source for deposition of thin film ferrites. The microwave voltage transmission and reflection coefficients from 7.8–10.5 GHz of mixed ferrite of composition $Mg_{0.8}Zn_{0.1}Mn_{0.1}Al_{0.8}Fe_{1.2}O_{4+\delta}$ in pellet form of different thickness are reported in this paper.

2. Experimental

The ferrite was prepared by standard ceramic technique [6] after premixing magnesium oxide, zinc oxide, aluminium oxide, ferric oxide and manganese carbonate in appropriate proportions and sintering at 1200°C for 40 hrs after pre-sintering at 900°C for 12 hrs. The formation of spinel ferrite was confirmed from XRD data as shown in Figure 1. The lattice

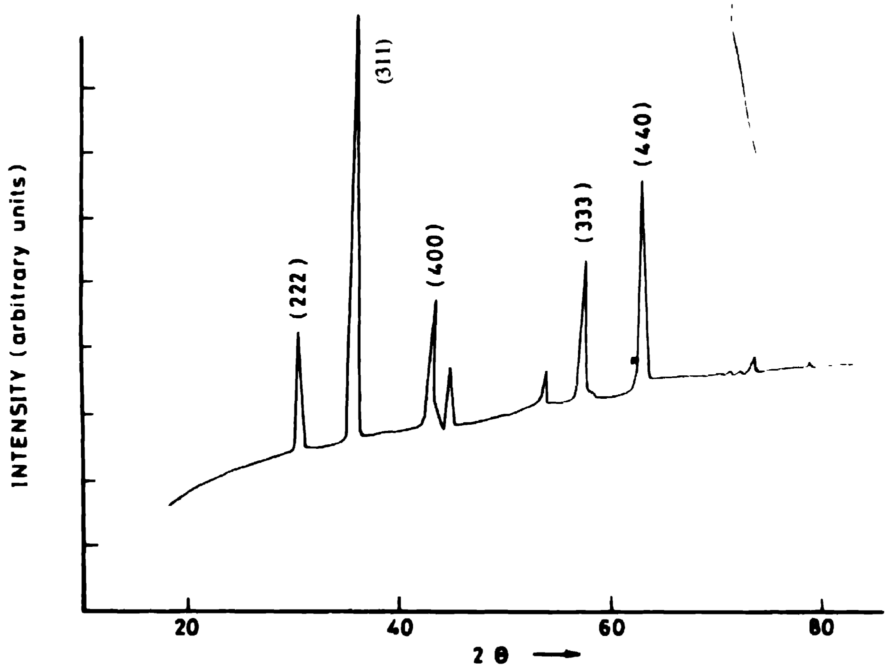

Figure 1. XRD data of $Mg_{0.8}Zn_{0.1}Mn_{0.1}Al_{0.8}Fe_{1.2}O_{4+\delta}$.

constant obtained was 8.34. They were also non-magnetic as seen by the absence of hysteresis loop. The mixed ferrite was made in pellet form of diameter 1.0 cm and of different thickness from 0.62 mm to 6.00 mm. The microwave measurements were taken in X-band waveguide set-up by keeping the pellet vertically with the broader face perpendicular to the direction of propagation inside the waveguide to coaxial adapter in the path of the microwave signal as shown in Figure 2. The measurement set-up consisted of a X-band signal generator (Gunn oscillator), isolator, attenuator, directional coupler and diode detector (Wiltron, USA). The X-band waveguide set-up was calibrated using a HP network analyzer. Except for slight attenuation below 8.2 GHz, the output wave form was quite steady and also the waveguide response below 8.2 GHz was also quite good. The oscillator did not give any output above 11.5 GHz. The transmission and reflection coefficients were measured using reverse connected directional coupler. The detector gave output in millivolts. The input and output voltages were measured to an accuracy of ± 0.001 volts.

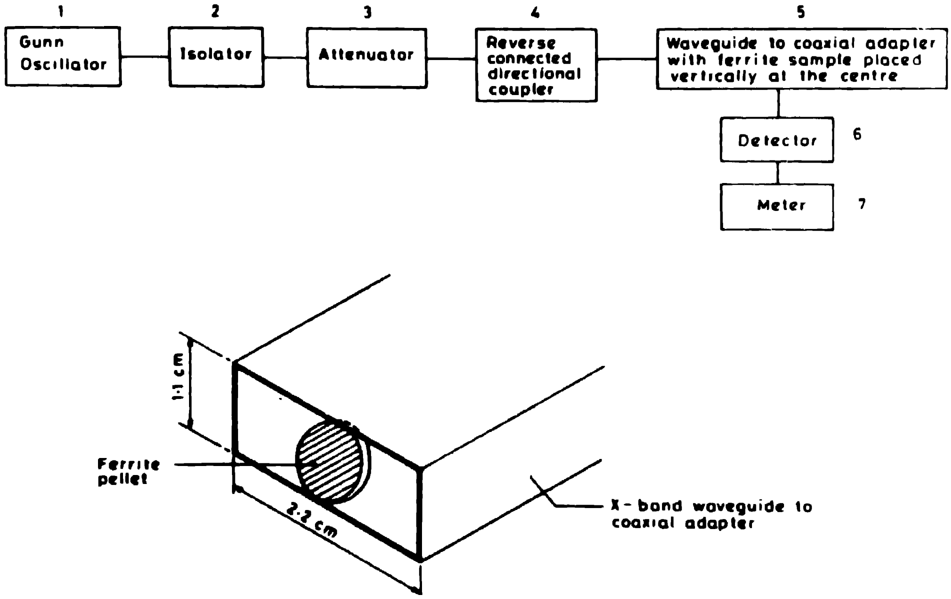

Figure 2. Schematic of position of pellet in the waveguide and block diagram of microwave measurement setup.

3. Results

Figure 3 gives the graph of thickness of pellet *versus* transmission coefficient for frequencies 7.9 GHz, 8.0 GHz and 9.0 GHz and Figure 4 depicts the typical curve of frequency *versus* transmittance for the ferrite of thickness 2.4 mm and above 5 mm. From Figure 3, it is seen that the transmission at particular frequencies shows a marked thickness dependence. For thickness from 0.62 mm to 0.84 mm, the transmittance becomes almost equal to 1 or slightly greater than 1 for frequencies 7.8–8.2 GHz and at all other frequencies the value being around 0.90. As the thickness of the pellet is increased beyond ~0.845 mm, the transmittance decreased to ~0.69 almost uniformly for all frequencies up to 10.5 GHz. The average transmittance remains at around 0.69 till a thickness of pellet of 2.4 mm. From 2.45 mm–5.00 mm thickness of pellet, again the transmittance showed values greater than 1 in the frequency range 7.8–8.2 GHz, the value reaching even to 2.5 at some thickness especially at 7.8 GHz and 7.9 GHz. Beyond 5.0 mm thickness, the transmittance again decreases to about ~0.67, though for lower frequencies the value is around 0.80. From Figure 4, it is seen that for other thickness the curve has tendency to peak at around 9.0 GHz, the transmittance becoming lower at higher frequencies. Table 1 gives the reflection coefficient and impedance data for some critical thickness of pellet. It is seen that for those thickness where transmittance is very high, the reflection coefficient also attains abnormally high values and corresponding impedance also increases.

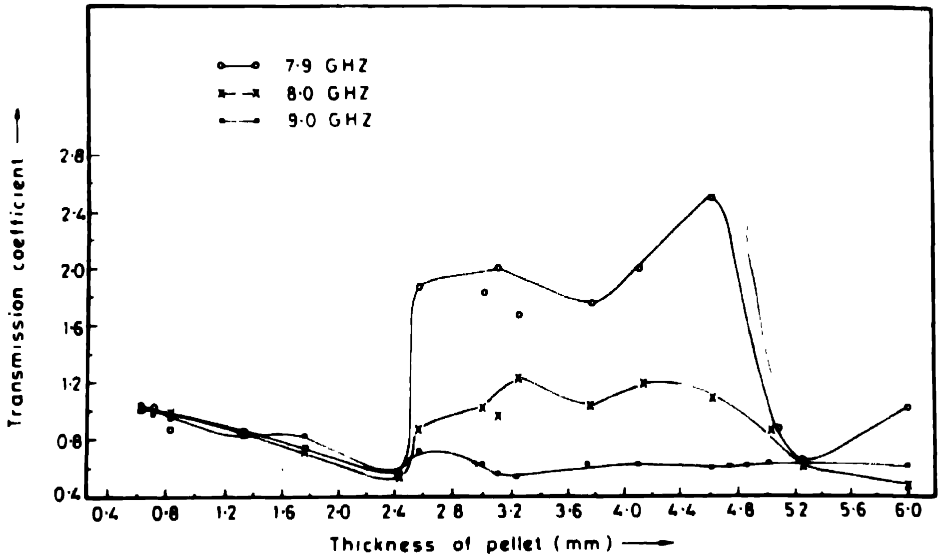

Figure 3. Thickness of ferrite pellet *versus* transmission coefficient for frequencies 7.9, 8.0, 9.0 GHz.

4. Discussion

Since the hysteresis data of these ferrites indicate that they are non-magnetic and no d. magnetic field is applied during microwave measurements, the ferrite in the waveguide can be considered to be like a dielectric medium with a dielectric constant of ~13.2 and tan δ ~3.5×10^{-4} [7]. In order to ascertain whether the dielectric effect is the only predominant factor, the transmittance of Al_2O_3 (dielectric constant ~10) pellets of same thickness as the mixed ferrites was measured. It was seen that the transmittance did not increase beyond 0.9 for any thickness or at any frequency. As the pellet thickness increases, there was decrease in transmittance to ~0.65. Since other pure dielectrics do not show voltage amplification type of phenomenon, it is specific for this particular ferrite at particular thicknesses. As the thickness of the ferrite increases, the effective dielectric constant of the composite air-ferrite guide increases, resulting in an increase in the interaction of the transverse r.f. vector in the ferrite for a given amount of input voltage. Since the ferrite is kept at the maximum position of r.f. field, the interaction is more. The total voltage transmitted gets modified due to the superposition of various modes generated due to the interaction. Modification of the voltage due to complex modes along with the dominant mode have been observed by workers [5,8,9]. Superposition of the various modes might be occurring at frequencies from 7.8–8.2 GHz so that the field assumes large values. The existence of hybrid character of ferrite modes causing shifts in resonance frequencies in unmagnetised ferrites, has been observed [10]. These spurious modes are size and position dependent. Residual magnetism does not seem to be the sole contributing factor since the pure $Mg_{0.8}$ $Fe_{1.2}$ O_4 samples did not show any amplification type results.

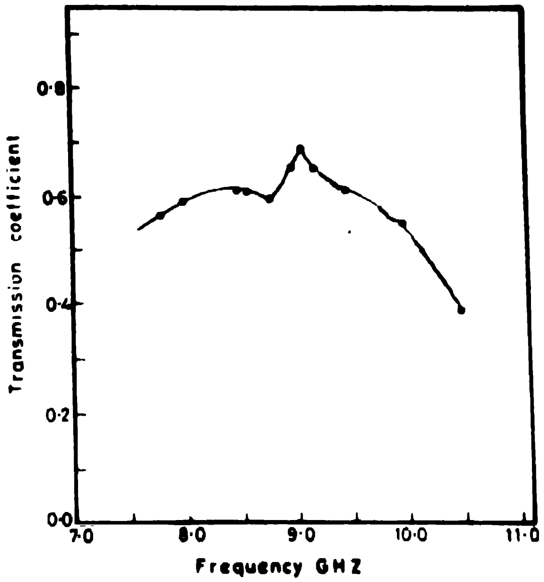

Figure 4. Typical curve of frequency *versus* transmittance for ferrite of 2.4 mm.

Another reason for high transmission coefficient (>1) might be due to internal reflections in the ferrite giving rise to box type resonances for particular frequencies. Also

Table 1. Microwave reflection coefficient and impedance data for different pellet thickness.

Thickness of pellet (mm)	Frequency (GHz)	Transmission coefficient	Reflection coefficient ρ	Impedance $Z_L = \frac{Z_0(1+\rho)}{(1-\rho)}$ Ω
0.62	7.9	0.98	0.04	54.2
	9.0	0.95	0.15	67.6
0.84	7.9	1.10	0.32	97.1
	9.0	0.94	0.14	66.2
2.45	7.9	1.82	0.43	125.4
	9.0	0.70	0.18	72.0
3.10	7.9	2.00	0.41	119.5
	9.0	0.65	0.12	63.5
4.60	7.9	2.50	0.44	128.8
	9.0	0.67	0.18	72.0
5.27	7.9	0.72	0.18	72.0
	9.0	0.69	0.14	66.3
6.00	7.9	0.90	0.16	69.0
	9.0	0.69	0.04	54.2

resonance response occurs when the incident wave frequency comes close to the material natural frequency. The sample acts as discontinuities which excites resonant fields inside the cavity of the waveguide. The excitation is equivalent to the appearance of intensive secondary magnetic line source at the place. The level of resonance amplitude will be a function of discontinuity location and width when the dimensions are of the order of $\lambda_{g/2}$ these resonances are more prominent. Due to multiple reflections occurring at the two ends of the ferrite pellet the path changes considerably. This effect depends on the dimensions of the ferrite *i.e.* its thickness and diameter and also on the frequency of operation. The amplification type process is found for pellet thickness in the range of $\lambda_{g/2}$ to $\lambda_{g/4}$ (6 mm–3 mm) for 7.9–8.2 GHz.

As the thickness of the ferrite increases beyond a certain limit, the dielectric waveguide effect becomes prominent and the ratio of energy in the ferrite to the total guide energy decreases and also the secondary modes start seriously interfering with the desired transmission properties, reducing the transmittance.

It is felt that a combination of various process takes place in the ferrite due to the action of microwave field which gives rise to very high transmittance and high reflectance at particular frequencies. The behaviour of the non-magnetic mixed ferrite of composition $Mg_{0.8}$ $Zn_{0.1}$ $Mn_{0.1}$ $Al_{0.8}$ $Fe_{1.2}$ $O_{4+\delta}$ cannot be explained simply on the basis of one particular effect, though dimensional resonance type of effect, interaction of the ferrite and also some crystal distortions [11] due to substitution of Mg^{2+} and Fe^{3+} ion by divalent and trivalent atoms may be some of the reasons behind the unusual microwave properties. These divalent and trivalent atoms being non-magnetic inclusions, the interaction with the r.f. field may not be uniform throughout the volume of the sample. The distortion in the spinel structure affects the distance between the neighbouring Fe^{2+} and Fe^{3+} ions and hence the magnetic ordering of the sample which in turn, affects the interaction of the magnetic moments with the microwaves.

Efforts are being made to understand this phenomenon and also see which particular compositions of the mixed ferrite give such results.

5. Conclusion

The preliminary investigations on the microwave properties of non-magnetic $Mg_{0.8}$ $Zn_{0.1}$ $Mn_{0.1}$ $Al_{0.8}$ $Fe_{1.2}$ $O_{4+\delta}$ pellets indicate a high thickness dependent phenomenon. When transmission coefficient is high, one expects the reflection coefficient to be very low. Since the ferrites investigated show abnormally high reflection coefficients in those regions of thickness where transmission coefficients are greater than one, it is felt that some complex dimension, composition and frequency-dependent phenomenon is responsible for the observed properties. More detailed study on this phenomenon is needed to ultimately choose suitable ferrite material for planar microwave circuits.

Acknowledgments

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